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THE DIRECT REDUCTION OF IRON AND THE LESS DEVELOPED AREAS

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THE DIRECT REDUCTION OF IRON AND THE LESS DEVELOPED AREAS

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Introduction

1. It is becoming apparent that revolutionary changes will occur over the next one or two decades in the world iron and steel industry. These changes will take place in two directions--in world iron ore trade, and in the construction of numerous small steel plants.

2. There are two driving forces which will bring this about. One is new technology which will permit large tonnage, low capital investment direct reduction operations to be carried out economically so that world trade in direct reduced iron as feed stock for the iron and steel industry will become practicable. The second is the rising tide of nationalism with its inevitable drive to promote local industry both in the form of small steel plants based on direct reduction as well as large plants for processing iron ore to the upgraded, reduced form, thus adding to the value of exports.

3. Steel production is the basic industry of the world's major powers. In fact, one can trace the history of the emergence of the great nations by their ranking in iron and steel production at any time over the past two to three centuries.

4. The fact that the annual steel output of the European Common Market has now reached 81,000,000 tons is a prime factor in the rapidly rising importance of this federation.

5. The great significance of steel to our civilization is more eloquently stated in an inscription on a French monument, "God made iron that men need not be slaves."

6. That the leaders of the less developed nations are well aware of the importance of establishing a steel industry is evidenced by the fact that international banking organizations such as the World Bank have been besieged with proposals to finance steel mills. Most of these proposals are unsound when analyzed by the international bankers on the basis of conventional technology and economics. Generally, this is due to the fact that the justified capacity is too small for the giant-sized conventional blast furnace steelmaking complex. Yet, there is little doubt of the need of a small steel mill in many of these less developed areas. One has only to look at the pattern of imports of these developing countries to realize that a small merchant rolling mill would supply nearly 60% of their steel requirements. Such a mill would save foreign exchange so important to the economy of these less developed nations, as well as provide employment. Ideally, such mills would consist of electric steelmaking furnaces for melting and refining scrap, facilities for casting into billet sized ingots, and a small versatile merchant rolling mill. Such facilities are common in selected locations in North America. The types of steel required for these products are not difficult

to produce and do not require the degree of skill necessary for the more sophisticated flat rolled product. What then is the problem? Could not such mills be built in the less developed areas and would they not be economical?

7. The difficulty with this solution is that it assumes that scrap of adequate quality and reasonable cost would be available to such a mill. Generally speaking, scrap is available only in the highly industrialized nations where steel has been produced for many years and where per capita consumption is now high.

8. The problem then is to provide means for producing a scrap substitute or melting stock at low cost from local raw materials (iron ore and fuels). Direct reduction represents a method of providing this melting stock (reduced iron) to supply the melting and refining operation of these small local mills.

9. What is direct reduction? Direct reduction has been defined in the past as the reduction of iron oxide at temperatures below the melting point of the reduced iron, and processes to accomplish this have been used since prehistoric times. However, direct reduction has now come to mean the reduction of iron ore in apparatus other than the pig iron blast furnace. We intend to show that some of the recently developed direct reduction processes represent a new dimension in the steel industry, both in terms of small steel plants and world trade in prereduced iron ore, which will be particularly important to the less developed areas. To fully understand the opportunities one must appreciate how the world's iron ore and steel industry presently operates and its changing economic and technological trends.

The Modern Large-Scale Steel Plant

10. The steel business as practices in the highly industrialized nations of the world is a very large industry. Iron is the dominant industrial product of our era. The coke blast furnace is the foundation upon which this industry stands. These large-scale integrated steelmaking operations have evolved and developed in those areas of the world where the three basic raw materials for the blast furnace--coking coal, limestone, and iron ore--could be brought together economically. Steelmaking in large integrated plants is carried out in three basic steps: 1) reduction of iron ore in the blast furnace; 2) conversion of the blast furnace molten pig iron (hot metal) and/or scrap to steel in steelmaking furnaces (open hearth, Bessemer converter, oxygen converter, or electric furnace) producing ingots (cast steel in primary form); and 3) finishing on rolling mills which break down the ingot to blooms, billets (small primary forms), and then to semi-finished steel products such as sheet, strip, rods, bars, plate, structurals, rails, etc. It is the first two steps up to the ingot stage of this process with which we are concerned.

11. The single, most important recent technical development in the steel industry is oxygen steelmaking, both in the oxygen converter and by oxygen injection into the open hearth or electric furnace. In either case, steel is now being produced in large integrated mills by the rapid oxidation of impurities in the molten pig iron (from the blast furnace) with gaseous oxygen. This new technique has resulted in increased production of steel per steelmaking furnace (open hearth or converter) and per man hour. For example, an open hearth furnace operating without oxygen on a conventional 50% hot metal, 50% scrap charge will produce steel at an average rate of 15-20 tons per hour. This same furnace with oxygen injection will produce steel at the rate of 30-40 tons per hour. Large oxygen converters have been built which produce up to 180 tons per hour. Oxygen steelmaking has resulted in increased demand in the steel mills for hot metal and has, therefore, emphasized the need to improve blast furnace operation.

12. Blast furnace output can be improved in many ways, most of which are additive. However, the most effective method is through the use of chemically and physically beneficiated raw materials. Today, the blast furnace operator is looking for the highest possible grade of ore and is expecting that it be physically prepared in the form of pellets or sinter. Furnaces fed with such prepared burden material operate more smoothly, produce more hot metal, and require less coke, with the result that the potential capacity of existing blast furnaces has been steadily increasing. The average iron content of the iron-bearing materials charged to the blast furnace in the United States has been steadily increasing, as is the proportion of physically prepared iron ore in the form of sinter and pellets in the blast furnace burden.

13. To offset the cost of these more expensive raw materials, the furnace operator is trying to effect further savings in coke by employing such techniques as injecting other fuels such as coal fines, natural gas, or liquid hydrocarbon fuels into the tuyeres of the blast furnace. Through the use of these improved techniques employing higher grade or beneficiated ores, physically sized burdens, higher purity coke, high top pressure, higher temperature hot blast, and blast moisture control, modern blast furnace operation is fast approaching the equivalent of minimum theoretical coke rates of 1050 to 1100 lbs. of coke per ton of iron. The next major step that can be taken to further increase productivity and reduce coke consumption will be through the use of prereduced ore in the charge. Thus, we will see the blast furnace gradually become converted to a gigantic cupola (melting furnace) whose output will be limited only by the ability of the cast house to handle the hot metal produced. Such operation will see further reduction of coke consumption down to as little as one-half of the lowest consumption per ton of hot metal realized today. This will come about by the use of large quantities of directly reduced iron ore produced in large-scale direct reduction operations carried out in those areas in the world blessed with the combination of iron ore (either high or low grade) and low cost fuels, i.e., natural gas, petroleum derivatives, or non-coking coals.

Iron Ore and Scrap

14. Iron units are consumed by the steel industry in three basic forms--iron ore, scrap, and pig iron. Iron ore and scrap are by far the most important in international trade.

15. While the major steelmaking centers of the world (United States, Europe, U.S.S.R., Japan, and the United Kingdom) were originally based upon abundant quantities of local ores, several, notably Japan, Europe, and the United Kingdom, are no longer entirely self-sufficient with respect to iron ore. As a result, there is a growing international trade in iron ore.

16. The world's steel industry is currently consuming about 500 million metric tons per year of iron ore. Of this amount, over 85 million tons per year of iron ore is involved in international trade (consider the ECSC as a single entity). In general, the major steelmaking centers still supply over 75% of their requirements from local sources. However, many of these local ores are relatively low grade and, with the resulting high slag volume, costly to reduce. Generally, imported ores are of the very highest grade.

17. With the anticipated growth in world steel production, it is inevitable that the major steel producing centers will import more and more raw materials. UN projections through 1975, extended through 1990 using generally the same basic projection method, indicate that annual steel production will increase from the present 399 million net tons (1961) to about 1220 million net tons (1990). This means that the annual consumption of iron ore will increase from the present 500 million metric tons (1961) to 1600 million metric tons (1990).

18. There is no question as to the adequacy of ore reserves throughout the world which have been estimated at 165 billion metric tons of exploitable, geologically explored iron ore reserves. However, by this time, the iron ore to feed this industry will come from many new mines and an increasing proportion of this iron bearing material will come from overseas via large, bulk, oceangoing ore carriers. The need to upgrade some portion of this vast tonnage to save transportation costs will become more pressing.

19. It is clear that there will be increasing competition between ore producers to supply the market. Increased competition has been evident even in the last several years, taking the form of price cutting, upgrading, and physical beneficiation to supply the very highest grade raw materials to the industry. North American ore producers are all going into production of pellets in order to sell the ore. The trend towards higher and higher grade iron-bearing raw materials will continue and the most logical next step is prereduction at, or close to, the mine.

20. Directly reduced iron ore would contain 90% iron and would be considered synthetic scrap, or melting stock. Thus, it would have to compete with scrap. What then is the situation in the world's steel industry with respect to scrap?

21. It is difficult to estimate the total annual volume of scrap consumed by the world's steel industry because much of it is derived from internal (in-plant recycle) and local sources. The availability of scrap in the various steelmaking centers depends in part on the steelmaking practice in use there. For example, in certain parts of Europe where the Bessemer or Thomas converters are the dominant steelmaking practice, scrap is abundant because these air-blown converters cannot consume much scrap. Conversely, in southern Europe where the open hearth process is the dominant steelmaking practice, scrap is scarce because the open hearth consumes large amounts of scrap, normally about 40-50 per cent of the charge.

22. Generally speaking, scrap is abundant only in the highly industrialized nations of the world and there is a growing international trade in the iron and steel scrap. If we consider the ECSC as a single entity, the international trade in scrap is about 7 million long tons per year. Of this amount, about 70% originates from the U. S. This is a good indication of the limited tonnages of scrap available for international trade. The ECSC and Japan are the major importing entities; the former accounts for about 40% and the latter about 30% of the total scrap imported.

23. Scrap is sold throughout the free world on a basis of "what the traffic will bear." Steelmakers have been plagued with widely varying scrap prices; high when steel production was up and demand was high, and low when steel production rates dropped. With the growth of oxygen steelmaking the demand for scrap will probably ease and prices will become more stable. At the present time scrap in the United States is at a near record low with prices at $20-$25 per ton. Prices will probably not go below this level as one could not justify the collection, preparation, and distribution costs.

The Forthcoming Revolution in Direct Reduction

24. The sweeping changes which we visualize in the world steel industry over the next twenty years will have as their foundation the rapidly accelerating science and technology of our times.

25. Technological innovations in direct reduction methods are being made in many of the Western nations. Work in this field has one aspect which is of particular interest to this conference. Most technical assistance to the less developed areas

involves the transfer of technology which has been applied for some time by the highly industrialized nations. In the case of direct reduction we have an example of new research and development which will first be applied in most cases by the less developed nations. In general, these new developments entail improved flexibility in handling very large, as well as small tonnages of ore per day, improved methods of generating reducing gases from natural gas and petroleum products, and better means of beneficiating and compacting the final product.

26. A partial list of the more recent direct reduction processes is presented in Table 1. One reason for the large number of proposed approaches to direct reduction is that no one process is best for all applications. Variations in local raw materials characteristics, local costs, size of operation required, and other factors will dictate the final process choice.

27. It is not possible in this paper to describe these processes in detail. However, such information can be obtained from the references as noted. In general, the processes can be broadly classified in two categories: those that employ gaseous reductants derived from natural gas or petroleum deposits, and those that employ solid fuels, usually non-coking coals or coke fines. A brief description follows of each category of process.

28. A typical gaseous reduction process involves as a first step the formation of a suitable reducing gas, such as a mixture of carbon monoxide and hydrogen from natural gas or fuel oil. This gas, heated to about 850 C, is then blown through a series of three fluidized bed reactors countercurrent to properly screened iron ore which is fed in the top of the first reactor and passes downward by gravity through the system. The fluidized bed reactors are capable of handling large tonnages of material continuously with excellent efficiency of gas utilization. The reduced iron product can be utilized directly or agglomerated for use as melting stock in various types of furnaces as shown in Figure I. If low grade iron ore is fed to the process the product can be beneficiated by grinding and magnetic separation. The flexibility of both process and product is evident. A variation on this process involves a batch process utilizing fixed bed rather than fluidized reactors.

29. Other points about this process are worthy of mention. Undesirable impurities in the iron ore, such as titanium and phosphorous, can be removed under certain conditions. In addition, it is possible to use direct reduction in combination with magnetic separation and further chemical processing to extract such materials as aluminum, manganese, nickel, chromium, etc. from iron-bearing ores which might not otherwise be feasible to treat economically. This could be of great interest in certain parts of the world.

30. The solid fuels direct reduction process steps are similar to the gaseous fuel method just described with the exception that a large, rotary kiln type reactor is usually employed, and any unburned coal or coke is recycled after magnetic separation through the kiln. The temperature of the kiln is carefully controlled by suitable gas or fuel oil burners located along its length.

31. The products of both general process categories are similar and can ordinarily be controlled to a range of 80 to 95 per cent iron, depending on the economics as dictated by product market. Agglomeration of the product is controlled to produce sizes best suited to end use. For iron blast furnace feed this would be small pellets and for synthetic scrap for steelmaking furnaces, larger briquettes.

The Economics of Direct Reduction

32. A modern blast furnace plant, the conventional method of iron ore reduction, involves an investment of approximately $75 per annual ton of pig iron capacity.

Thus, a 1,000,000 ton per year blast furnace (2) plant together with required coke plant facilities, requires an investment of about $75,000,000. The investment requirements of direct reduction plants of equal capacity are approximately $56 per annual ton for HyL; $67 for H-Iron; $49 for ADL; and $45 for R-N. Thus, a 1,000,000 ton per year direct reduction plant would involve an investment of $45,000,000-$67,000,000, or a saving of 10-40 per cent over the blast furnace.

33. The cost of producing melting stock via these direct reduction processes varies from about $18 to $25 per ton based on fuel valued at 20 cents per million BTU's and ore costs at market, or $6 to $9 per ton, and labor costs of $1.60 per hour. While the range of these costs is large, they can be estimated quite accurately for a particular situation where raw materials, labor, etc. component costs are known. This range of costs compares with pig iron costs of $40-$50 per ton from the blast furnace. These figures are not entirely comparable since the blast furnace produces molten pig iron, whereas the direct reduction product is ordinarily a cold melting stock of very high purity. Thus, it is more logical to evaluate this melting stock by comparing it with the price of scrap or the value of beneficiated iron ore. The price of scrap in the United States is ordinarily about $30-$35 per ton. Direct reduced melting stock might attain a higher value as it is lower in metallic impurities, is more constant in composition, and better sized to suit end use. The evaluation of direct reduced melting stock as a blast furnace or hot blast cupola feed material is a more difficult task. Here one will require experience in order to set prices. Two observations can be made at this time. First, utilizing about ten per cent melting stock (90% Fe) in a blast furnace charge, calculations show a $2.00 per ton saving in hot metal cost when the melting stock is priced conservatively high at $41 per ton. The savings come about because of lower coke and limestone consumption and increased hot metal output. One can easily visualize slowly converting the blast furnace into a giant cupola as the trend is continued toward feeding higher and higher percentages of melting stock. Second, direct reduced melting stock has been stated on the basis of experience to date to be valued above scrap as a hot blast cupola charge because of the absence of metallic impurities. Thus, it appears that the largest future market for direct reduced melting stock will be in supplying the major steel centers of the world with upgraded raw material for the blast furnace or hot blast cupola feed to produce hot metal, and to a lesser extent as synthetic scrap for use in feeding steelmaking furnaces.

34. The advantage of carrying out the reduction step near the mine site in order to save shipping weight is obvious. Those nations blessed with both iron ore and inexpensive fuel are in a position to supply the steel centers of the world with very large tonnages of superior iron-bearing raw materials. Such operations would utilize local fuels, such as natural gas, which might otherwise not be used for many years. In a sense, one could say that direct reduction would provide a means of exporting fuel and would raise the value of the ore exported from about $6-$9 per ton to about $25-$35 per ton.

Small Local Steel Plants

35. The per capita consumption of steel today in most less developed areas seldom exceeds 20 pounds per year. This means that requirements for small local steel mills would begin in the range of 40,000 to 200,000 tons per year. Nevertheless, with the projected expansion in world steel requirements previously mentioned, we visualize a substantial increase in production in countries not now producing steel. This production will probably reach about 100,000,000 tons per year by 1990. Since a conventional blast furnace and steel plant can seldom be justified at less than 1,000,000 tons per year capacity, the answer must be found by another route. World trade in scrap is so limited in tonnage that small steel plants based on scrap will not provide the answer. Thus, we turn to direct reduction.

36. There are several bases upon which small steel plants may be justified in the less developed areas. If costs of fuels and raw materials are low enough, this alone might permit straight economic justification even at relatively small scale. A small steel plant might be made economical by operating on a fractional portion of the product from a large scale direct reduction operation supplying melting stock to the world market. In this case, the small melting, casting, and rolling operations would benefit from the improved economics of the large scale reduction operations. If large quantities of directly reduced synthetic scrap were available at moderate prices, this might also justify small local mills in those areas not blessed with iron ore. If the political atmosphere is such that added employment, independent supply, savings in foreign exchange, etc. would override in importance strict economics, small mills will be justified and built.

37. The local steel plant would consist of a direct reduction unit scaled down to proper sizes to meet requirements. Fortunately, many of the direct reduction processes can be scaled down and yet operate efficiently. The product from the reactors would be fed to a steelmaking furnace, probably electric, and the steel cast into billet-sized ingot molds or continuously cast to avoid the high cost of a primary breakdown mill. The billets would then be fed directly to the rolling mill.

38. A plant of this type would cost about $8,000,000 for 40,000 tons per year capacity and $28,000,000 for 200,000 tons per year capacity. It could supply many of the less expensive, easiest to produce types of steels and steel products normally required by the less developed areas. The typical consumption pattern for these areas is as follows:

Product	% of Total Consumption
Reinforcing Rods	30
Rounds	10
Light Structurals	7
Wire	10
Total Merchant Products	57
Sheet and Plate	12
Galvanized Sheet	5
Tinplate	7
Total Flat Products	24
Pipes and Tubes	12
Miscellaneous (Primarily Rails)	7

39. The merchant products, including bars, rounds, light structurals and wire, could be produced in a small merchant mill supplemented by wire drawing equipment. In addition, some skelp for pipe and tubes might be produced. More sophisticated steel products which represent only about 40 per cent of requirements would still have to be imported.

40. Capital and operating costs for such mills can be estimated quite accurately when local cost figures are provided. In the absence of such figures, we estimate the common merchant mill products could be produced in the range of $90 to $110 per ton.

The Future

41. By 1990 world production of steel is expected to increase threefold. There is opportunity for many of the less developed areas of the world to participate actively in this growth through the utilization of direct reduction.

42. The additional supply of iron units required for the expansion of steel production must come from iron ore. Tonnage supplies of scrap are limited. Iron is one of the most abundant and widely distributed elements in the earth's crust, representing about 4 percent of the total. Its supply is essentially limitless in almost all regions of the world. The areas of the world where natural gas and oil deposits, the major fuels for direct reduction, are known, are numerous and are expected to increase. Thus, opportunities to participate in the production of prereduced iron ore for world trade and small steel plants are legion. Among the many nations faced with this challenge are Algeria, Argentina, Brazil, Burma, Canada, Colombia, Egypt, India, Indonesia, Iran, Israel, Liberia, Mexico, Morocco, Pakistan, Peru, Thailand, Trinidad, Turkey, Tunisia, and Venezuela.

43. A new dimension is being added to our potential for steel production and it is up to all of us to understand its significance and possible application in the forward movement of our civilization now and in the future.

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TABLE 1 - THE NEWER DIRECT-REDUCTION PROCESSES

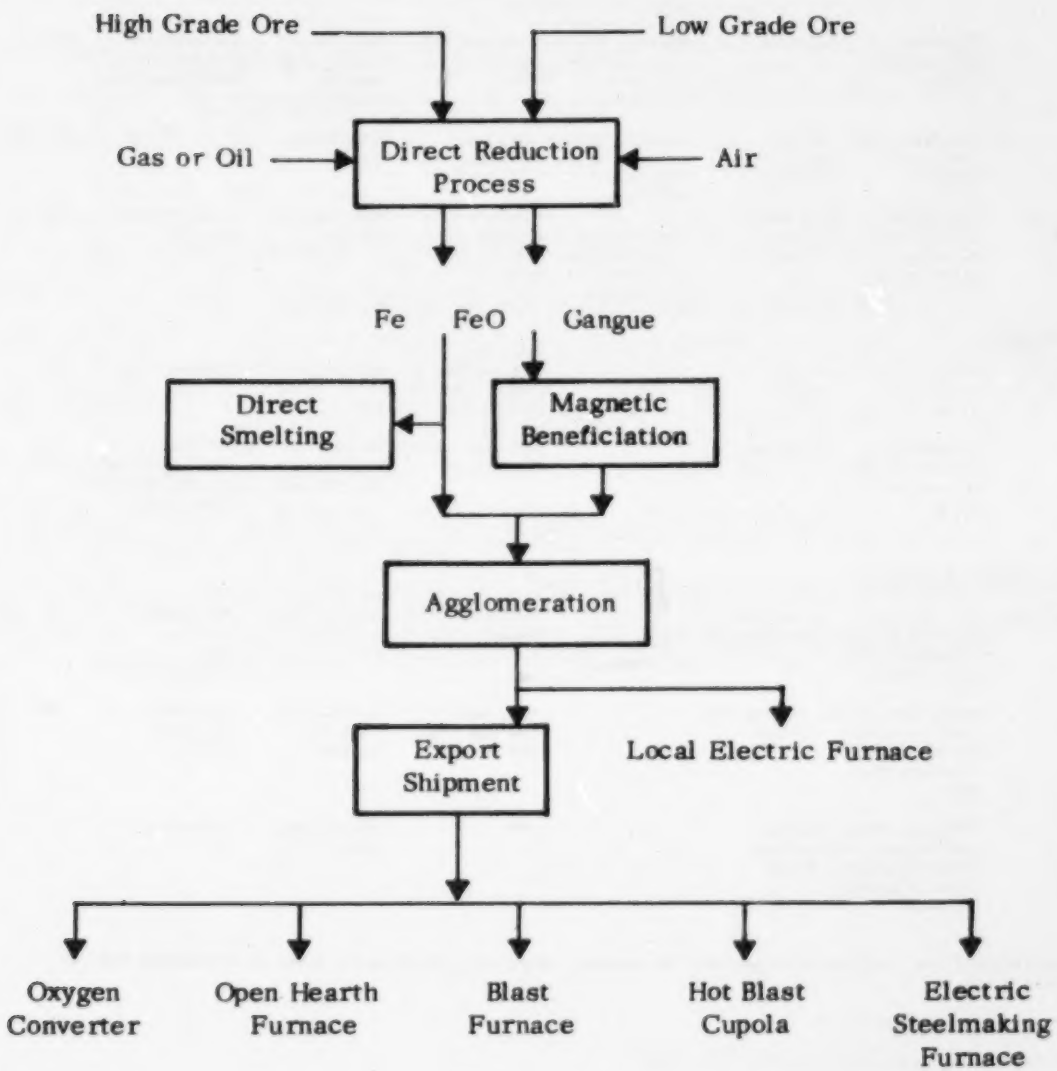
Process Name	Type of Equipment	Reductant (*)	Reductant Produced How	Ore	Final Product	Developer, Licensee, Etc.	Reference
Gaseous Processes							
HyL	fixed-bed reactor	hydrogen, carbon monoxide	catalytic steam reforming of nat. gas	rich lump ore, pellets: up to 1¼", max 20% - ¼ in.	sponge iron, 85% reduced	Hojalata y Lamina, M.W. Kellogg Co.	(1) (2)
H-Iron	fluidized-bed reactor 3-stage	hydrogen	partial oxidation, water-gas shift, scrubbing	hi-grade mag. conc'e mill-scale	low-C iron powder, 98% reduced briquet'd	Hydrocarbon Research Inc.; Bethlehem Steel	(2)
A.D.L.	fluidized-bed reactor, 3-stage	carbon monoxide, hydrogen	partial oxidation of nat. gas or oil with air	various, 1/8 in.	briquettes, 85% red.	A. D. Little, Inc.	(2) (3) (4)
ACAR (Allis Chalmers)	traveling grate, dual concetric kiln-within-kiln	hydrogen, carbon monoxide	cracking of hydrocarbons w. steam or air within kiln	hi-grade conc. pellets 1/2-3/4 in. diameter	iron pellets 81% Fe	Allis-Chalmers Mfg. Co.	(5)
Kiln Processes							
Freeman	rotary kiln, co-current fired	solid carbon fines		mag. or hem. conc's, 1/2-1 in. pellets	sponge pellets, 91.5% Fe*	Freeman Corp.	(6)
R-H	rotary kiln, countercurrent & internally fired	solid carbon fines		various, -1 in. + 20 mesh	briquettes or sponge, abt 90% red.	R-H Corp. (Nat. Lead Co. and Republic Steel Corp.)	(7)
Electric Furnace Processes							
Strategic-Udy	rotary kiln, countercurrent-fired, & electric furnace	solid carbon fines	. . . . .	various, -3/8 inch	molten iron 1-2.5% C	Strategic Mat'ls. Corp., Koppers Co.	(2) (8)
Ocarb	preheating kiln, balling drum, rotary kiln, electric furnace	coking coal fines	. . . . .	mag. conc's low P&S, 50%-100 mesh	molten pig iron-2% carbon	Swindell-Dressler Corp.	(9)
Dwight-Lloyd McWane	"Flying Saucer" pelletizer, D-L sintering machine, electric furnace	solid carbon fines	. . . . .	**	molten pig iron	McDowell Co.	

* "Solid carbon fines" indicates in general coke breeze, char, etc., anthracite fines or bituminous coal of subcoking grade.

** Not specified in literature.

General references: (10), (11), (12), (13), (14)

FIGURE I - POSSIBLE DIRECTLY REDUCED PRODUCT



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